Analysis of Civil Helicopter Accidents

Presented by Sandra Hart* on behalf of the Helicopter Accident Analysis Team

at

HeliExpo ‘98

February 15, 1998

*** Army/NASA Rotorcraft Division**
Ames Research Center
Moffett Field, CA

% Helicopter Accidents by Event

From HAI Quarterly reports (1986-1996); n=1852

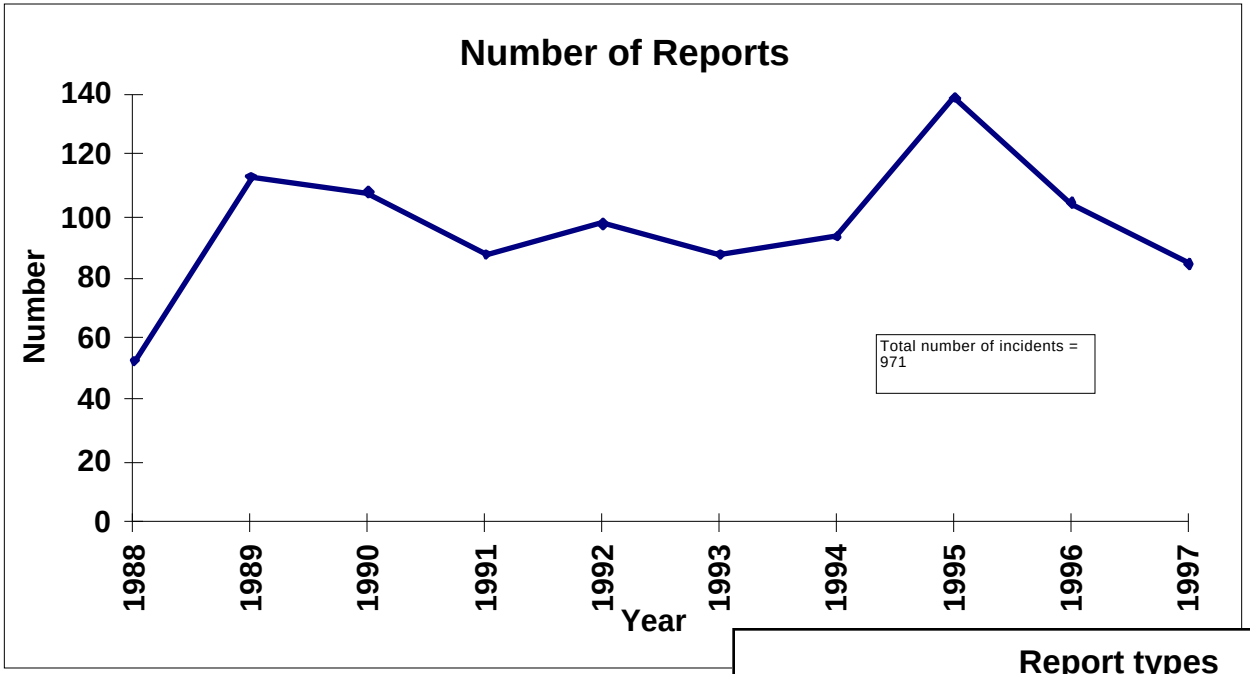
Category	Percent
Pilot error	21%
Engine	17%
Misc	12%
Loss of Control	11%
Collision w/object/ground	8%
Autorotation	7%
Wirestrike	5%
Maintenance or material	7%
Weather	4%
Loss of tailrotor control	3%
Fuel starvation	2%
Foreign object damage	2%
Ground coord	2%

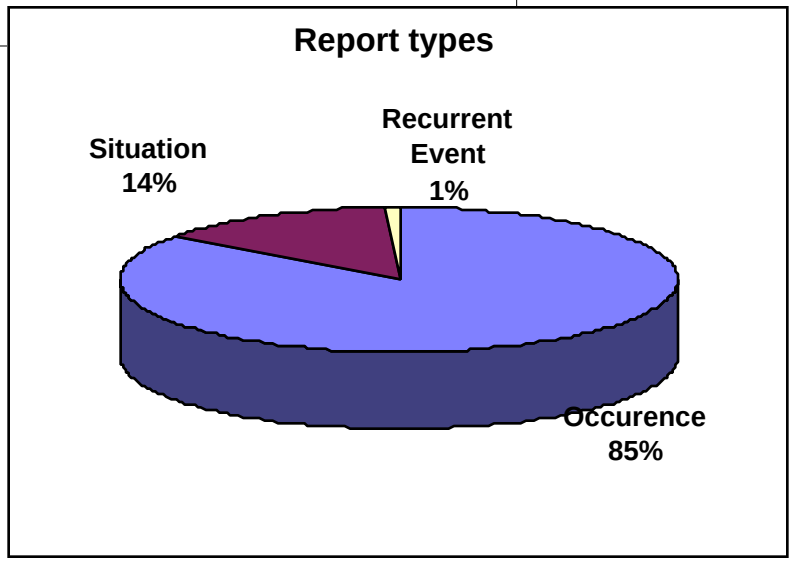
% Helicopter Accidents by Type of Operation

From HAI Quarterly reports (1986-1996); n=1911

Category	Percent
Part 91 - Personal	20%
Part 91 - Instruction	14%
Part 91 - Other work	13%
Part 137- Air applications	11%
Part 135- Air Taxi	10%
Part 91 - Business	8%
Part 133- External load	6%
Part 91 - Ferry	2%
Part 91 - Airborne obs	4%
Part 91 - Positioning	4%
Part 91 - Public use	4%
Part 91 - Air applications	3%
Part 91 - Executive/corp	1%

Initial Analysis of ASRS Incident Data





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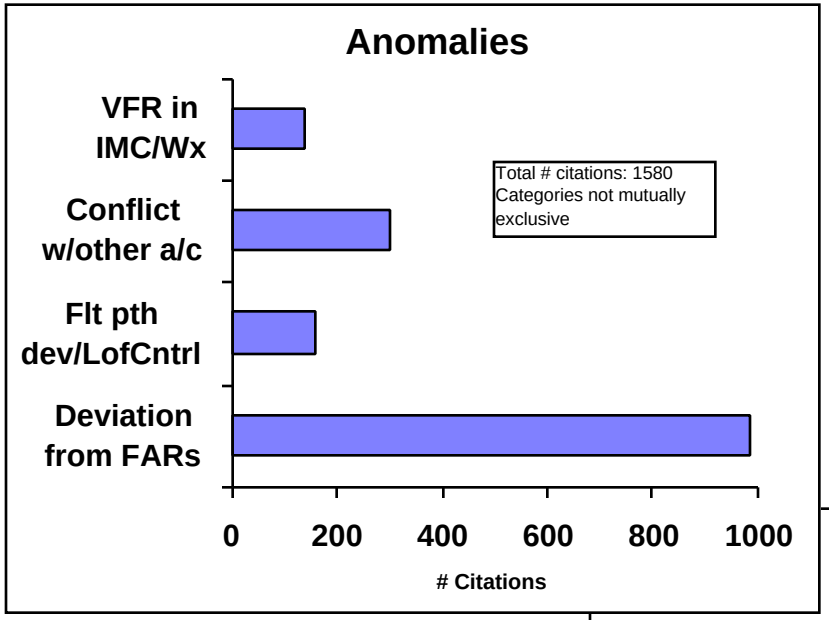

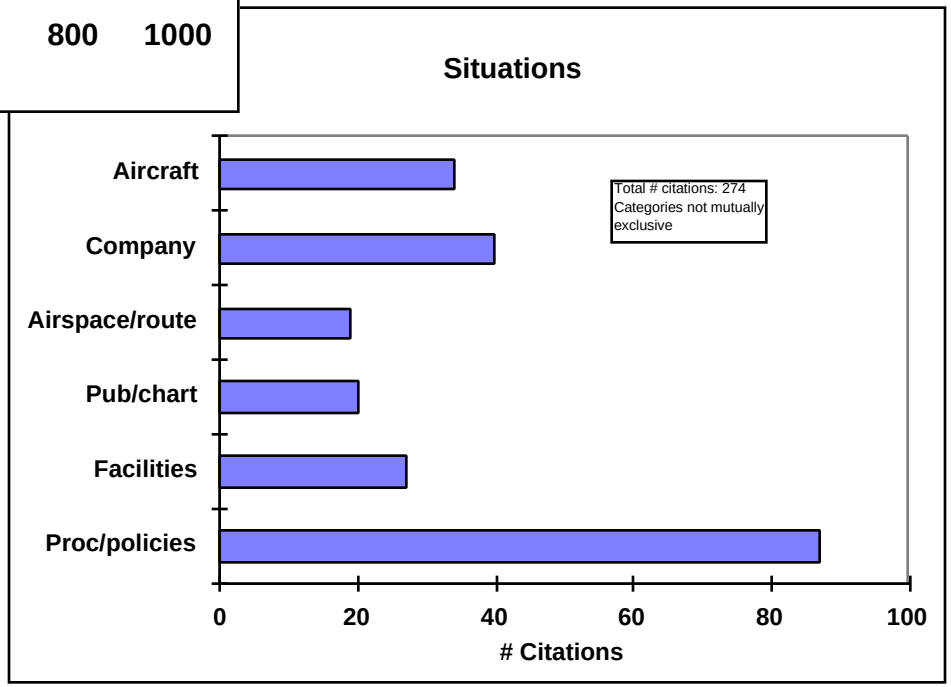

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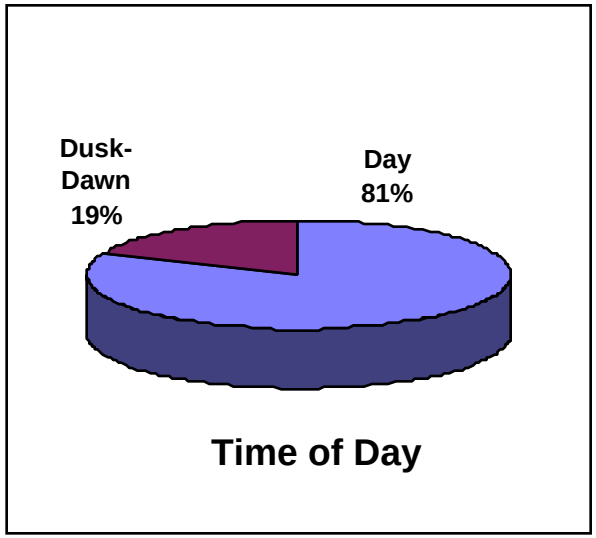
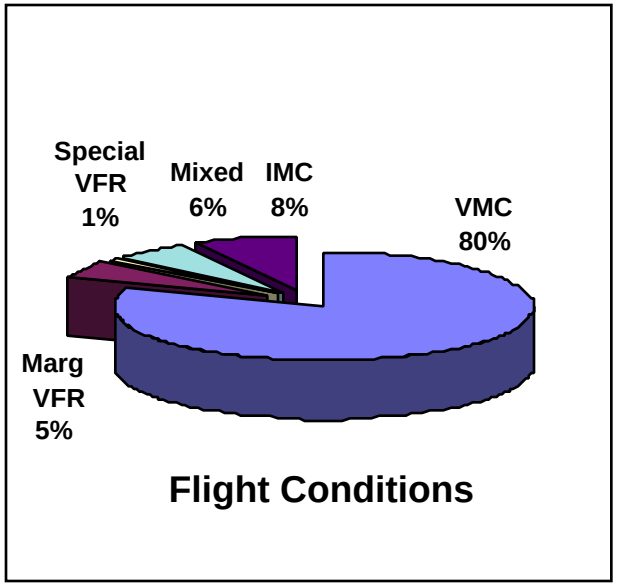
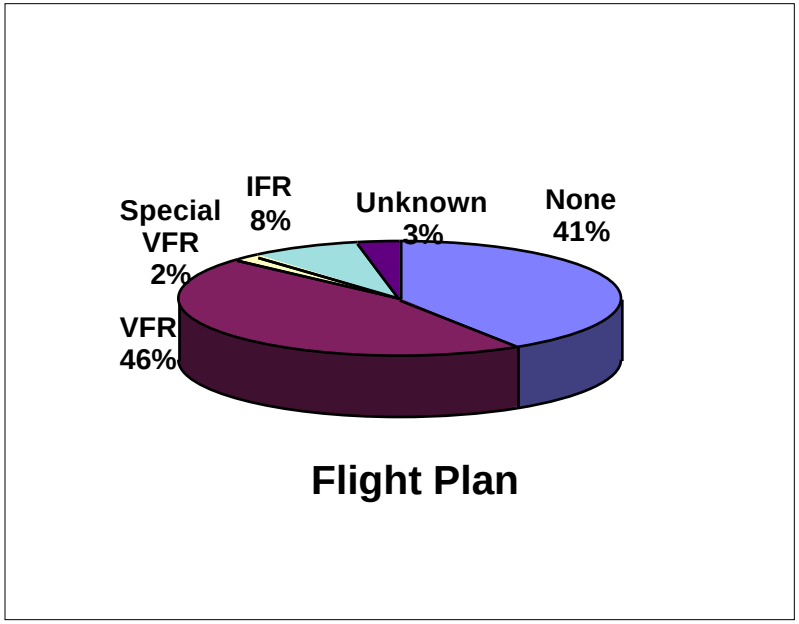


Time of Day

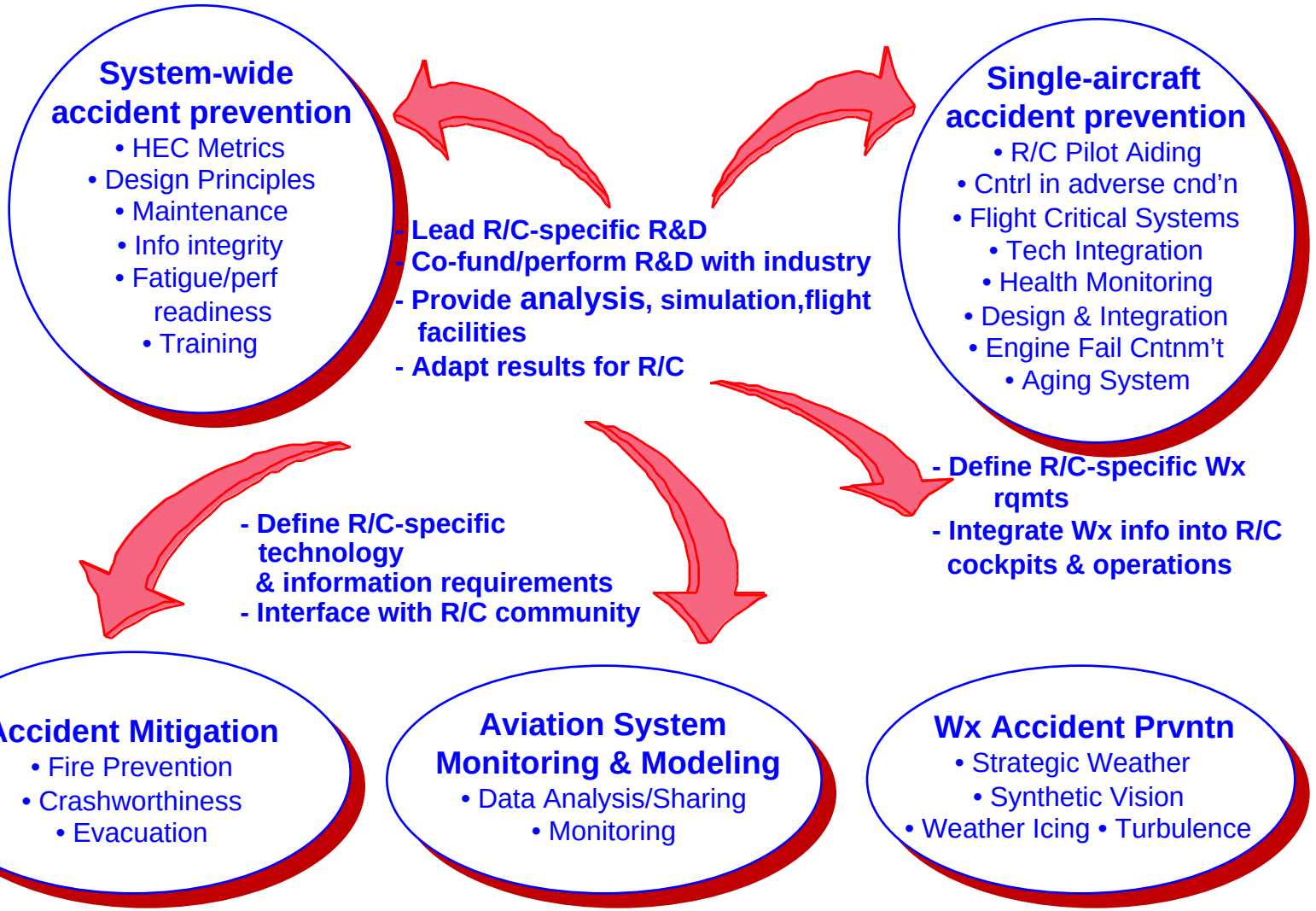


Flight Conditions



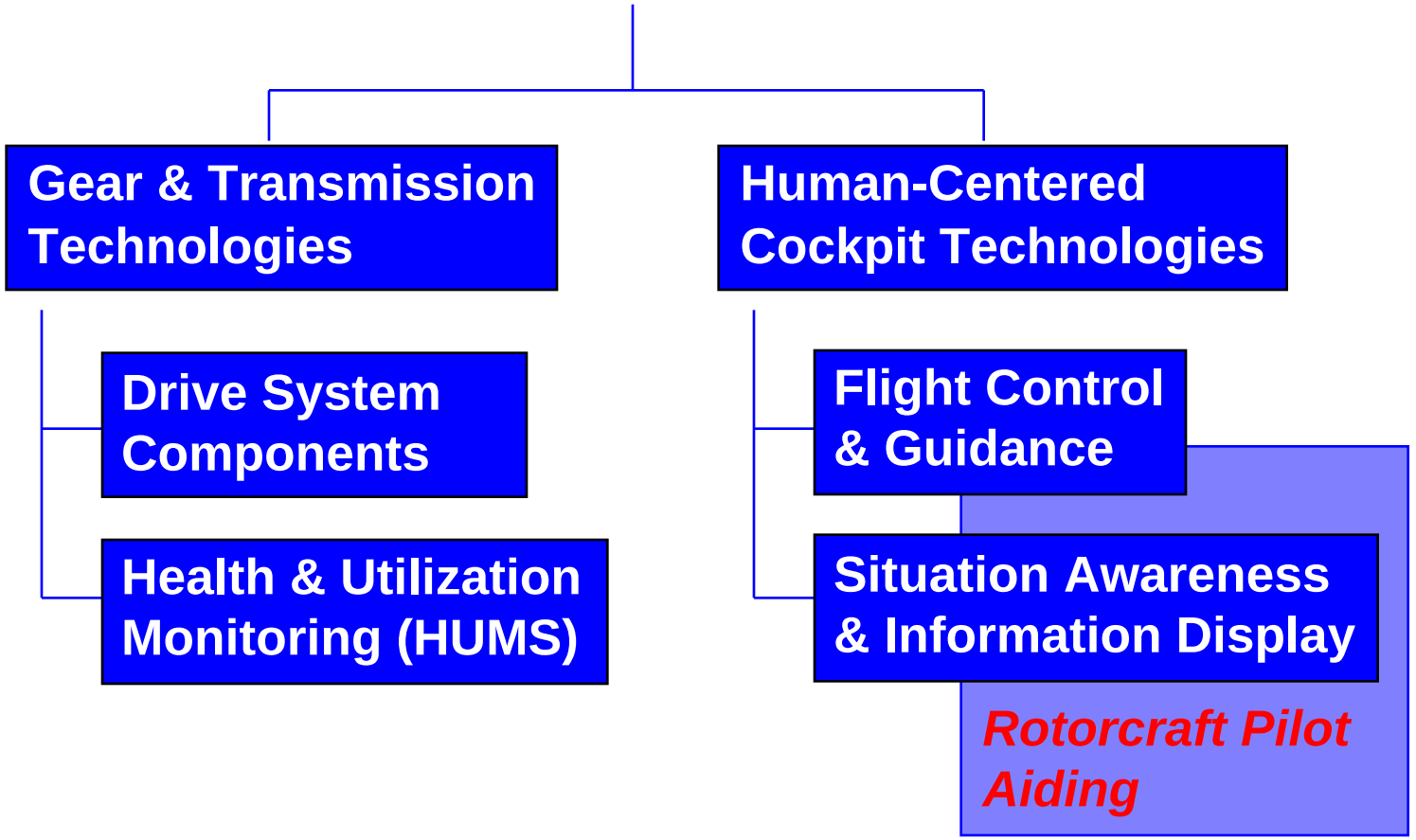
Flight Plan

Initial Role of Rotorcraft in Safety Program



Safe All-Weather Flight of Rotorcraft (SAFOR)

Goal: Reduce the rotorcraft accident rate attributable to human factors and drivetrain malfunctions by a factor of five by the year 2007



SAFOR Human-Centered Cockpit Tech

	Flight control & Guidance Tech	Situation Awareness & Info Displays
Prevention (Safety by Design)	Reduce pilot workload with: - Control system design tools - Partial authority SAS & ACAH	Reduce pilot workload thru: - Valid SA & perf models & measures for display design & evaluation - SA training module
Intervention (Real-time aiding)	Eliminate inadvertent envelope exceedence w/real-time pred, meas, cueing, and limiting for critical parameters & components	Avoid degraded perf thru: - Eval civil use of NVGs - Integrated display of clrnc, map, Wx, position, hazards
Mitigation (Recovery from a bad situation)	Ensure safe ops & handling qualities following loss of SA, failure of FCS, or single engine thru active control technology, trajectory optimization	Remedy impact of loss of SA, critical sytems recovery aids & displays

Safety-Related Work Performed under RITA/NRTC*

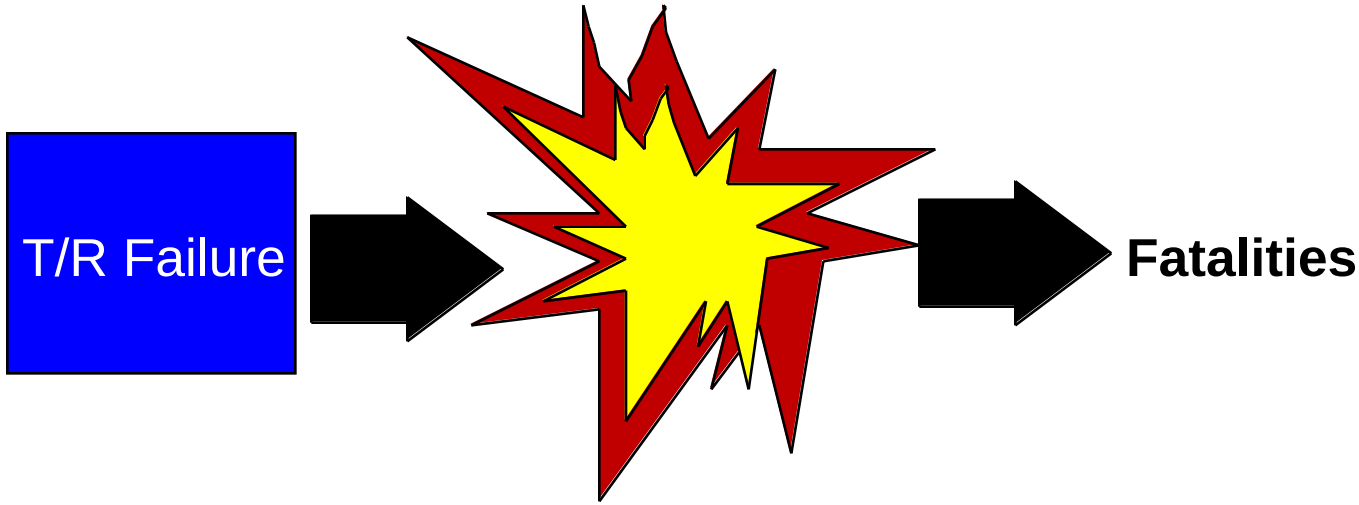
- **Aging Systems**
  - Damage Tolerance Technology for Helicopter Structures
  - Field Corrosion and Fretting Fatigue Technologies
  - Composite Struct.Design, Certification, Strength/Life Prediction
- **Health Monitoring**
  - Health and Usage Monitoring Systems (HUMS)Technology
  - Structural Flight Loads Monitoring
  - Cockpit Situational Awareness
- **Design Principles**
  - UltraSafe Transmission Design
- **Rotorcraft Pilot Aiding**
  - Helicopter Operations/Approach Using DGPS
  - Rotorcraft Collision Avoidance
- **Synthetic Vision**
  - Synthetic Vision and 3D Display
- **Weather Icing**
  - Rotor System and Inlet Icing Protection Technology
- **Systems Approach to Crashworthiness**
  - Crash Safety / Bird Strike

*** Rotorcraft Industry Technology Assn**
National Rotorcraft Technology Center

An Accident Sequence

Precipitating Event

Accident



Potentially Available Information

Coded data:

- ***Who:*** **Factual data about pilot, helicopter, company**
- ***When:*** **Time of year/day; phase of flight**
- ***Where:*** **Location, terrain, water/land, weather**
- ***What happened*****: Consequences (Event, Fatalities,...)**
- ***Why:*** **Probable cause/contributing factor codes**

Narrative data:

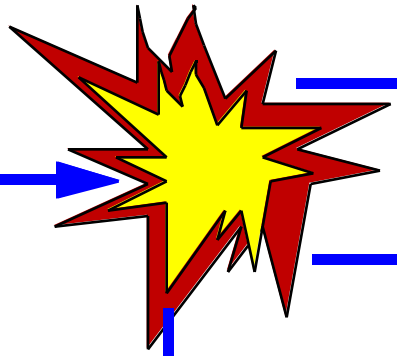
- ***Who:*** **Interviews, medical rpt, maintenance records, first-hand reports, etc**
- ***Where*****: Maps, photos, description, flight plan**
- ***What happened*****: Witness reports, survivor interviews, commo transcript, investigator's summary**
- ***Why:*** **Investigator's inference about immediate cause(s), contributing factors, interviews, supporting docs**

To Achieve Goal of Reducing Future Fatalities

Prevent **precipitating event**

Intervene **to ensure pilots respond well to hazards/failures**

Mitigate **impact of an inevitable accident**



Fatalities

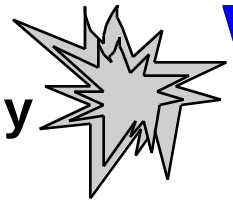
Initiated flt foll/flt plan quick rescue

Crsh-wthy seats, restraints, no fire

Minor injuries

T/R Fails

Plt auto-rot successfully



No injuries

do not Maintainers do detect & replace failing part

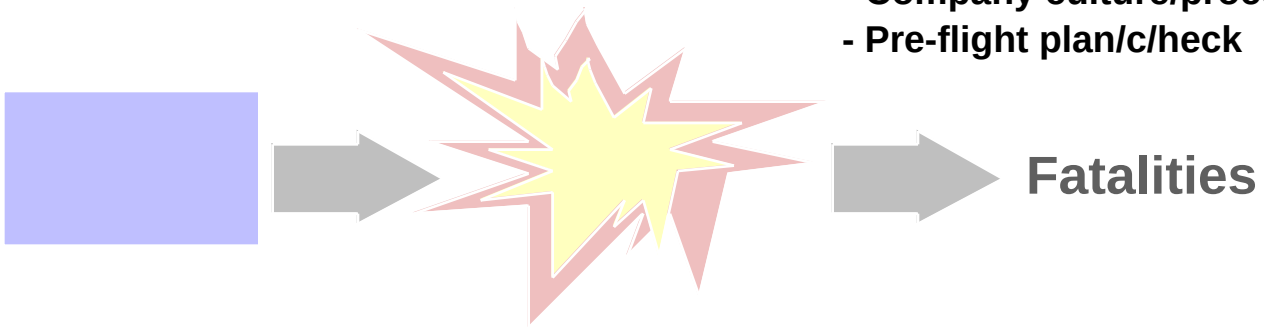
HUMS detects prblm; alerts plt; return to base

No Accident

Missing Information

To identify accident prevention & mitigation opportunities, more must be known about typical chains of events than in existing databases

Flight readiness
- Pilot state, time on duty, relevant experience
- Helicopter readiness
- Company culture/procedures
- Pre-flight plan/c/heck



Details
- Pilot's actions, internal comm
- Vehicle parameters
- Immediate env cond
- Human factors data

System-wide information
- Link between incidents (precursors) and accidents
- Baseline data: exposure time, normal practices

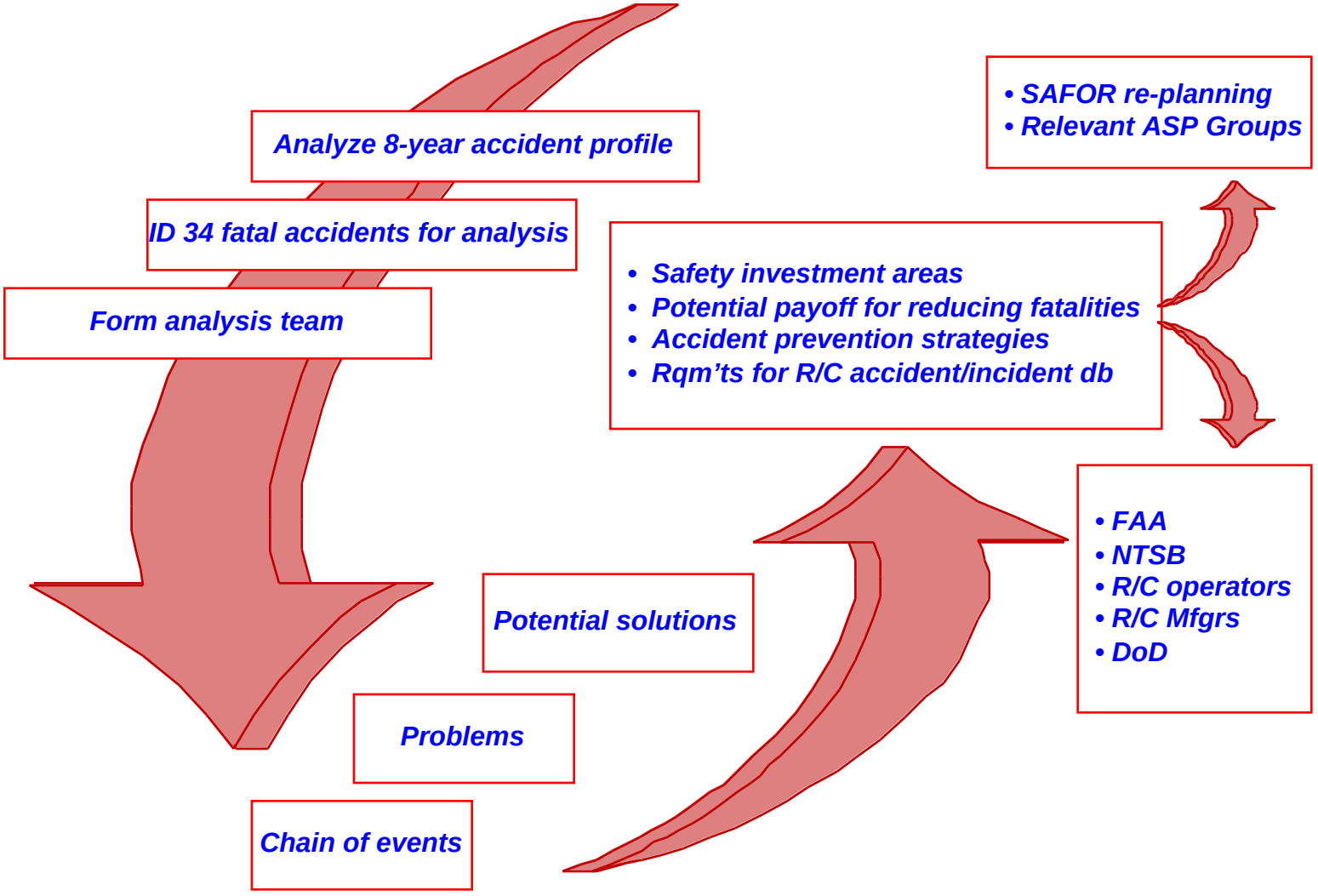
Accident Analysis Rationale

- Accidents are the result of a chain of events, rather than a single cause
- Future fatalities might be reduced by altering or eliminating one or more of the “links” in the chain
- Accident-prevention strategies can be identified by analyzing what happened in previous accidents (the chain of events) and brainstorming about what might have been done differently (potential solutions)
- Accident reports offer a window into civil helicopter operations through which system-wide problems can be identified

Accident Analysis Objectives

- Develop a list of accident prevention strategies based on detailed reviews of fatal helicopter accidents
- Assess the probable effectiveness of solution strategies upon reducing future accidents
- Recommend high-payoff research and technology development areas

Accident Analysis Overview



Accident Analysis Methodology (Preparation)

- Establish criteria for selecting accidents
  (at least one fatality; NTSB report available)
- Select team members
  (manufacturers, operators, relevant govt agencies)
- Address confidentiality issues
  (use publicly available data; accidents and brainstorming data confidential)
- Downselect accident subset:
  - Representative topics: pilot error, equipment failure, obstacle strike, weather, over-water, post-crash fire
  - Representative circumstances: flight conditions; type of operation; phase of flight; vehicle type
- Distribute full NTSB reports to team members

Team Members

Industry:

- Bell Helicopter Textron (Fox)
- The Boeing Co (Isbel, Wroblewski, Plaster)
- Sikorsky Aircraft Corporation (Cooper)
- Robinson Helicopters (Bressler)*
- Petroleum Helicopter, Inc (Old)
- National Helicopter (Smith)
- Columbia Helicopter (Warren)

Government:

- NASA (Elliott, Hart, Zuk, Dearing, Studebaker, Coy)
- US Army/NASA-ARC (Shively)
- FAA (McHugh, Wallace*, Smith)
- Battelle/ASRS (Morrison, Dodd)
- US Army Safety Center (Hicks)*
- NTSB (Borson)*

* Were unable to attend most or all of the meetings

Characteristics of Accidents Analyzed

By Year

Year	%
1989	6
1990	24
1991	32
1992	6
1993	6
1994	26

By Phase of Flight

Phase	%
T/O	3
Climb	2
Cruise	24
Desc/Appr	8
Lndg	3
Mnvr'g	17
Hover	7
Other	3

By NTSB Event Code

Code/Event	%
130 Sys malfunct	10
220 Collision w/ object	13
230 Collisionwith terrain/water	22
240 Inflt encounter w/Wx	9
250 Loss control inflight	18
270 Mid air	4
350 Loss of engine power	18

By Manufacturer

Mfg	%
Augusta	2
Aro'sptl	9
Bell	22
Hughes	12
MBB	4
MDH	6
Robinson	7
Sikorsky	3
Other	2

By Type of Operation

Type	%
Part 137	3
Pub Use	6
P-133	6
P-135	18
P-91	68

Methodology (Analysis Meetings)

- For each accident, 3 sub-groups:
  - Developed a sense of what happened from the text of the full report - - generated a Chain of Events
  - Brainstormed about Problems/Issues (looking beyond those immediately responsible for the accident)
  - Brainstormed about Solutions (what might have eliminated each link in the chain of events)
- Full team developed a complete list of Events, Problems, and Solutions
- Event, Problem, and Solution databases were "coded" to facilitate analysis and summary

Example of Analysis for One Accident

Event #	Chain of Events
1	Load pax
2	Preflight helio
3	Begin takeoff
4	Lost altitude
5	Ditched in lake
6	Helio capsized/sank
7	One pax drowned; trapped in seatbelt
8	Rescue delayed

P#	RelEvnt	Problem	Problem Category
1	1,6	Preflt brief too brief; no demo	Pax safety brief
2	2	Unclear-seatbelt demo done?	Info missing/incomplete
3	2	Power chk not done	Sense of urgency
4	2	No accurate wind information	Local/enroute Wx
5	3	Took off down wind	Plt failed to follow proced
6	4	Didn't monitor alt/spd	Plt diverted attention
7	6	Didn't arm/deploy floats	Plt failed to follow proced
8	6	Vehicle capsized then sank	Crshwrthns: imprv floats
9	7	Pax didn't/couldn't release seatbelt	Crshwrthns: imprv restraints
10	8	Rescue delayed - - no flt following	Automated flt following

S#	RePrb	Potential solutions	Solution categories
1	3	Require pax briefing in helio w/demo	Safety culture
2	3,5,6	Improve pilot training	Training
3	3,5	Discourage hotdogging	Safety culture/Env limiting
4	4	Lo-cost local wx info at dispatch	PC-based pre-flt planner
5	5,6	Better cockpit displays/warning	Real-time perf monitor
6	3,7	Electronic checklist-warn if miss step	Pilot aids
7	10	Low cost, automated flt following	Flt following
8	2	Record crew actions/vehicle state	CVR/FDR

Methodology (Wrap-up Meeting)

- Define protypical Chains of Events (illustrate problems/potential impact of solutions with hypothetical accidents)
- Summarize Problem categories; define
- Cluster prevention strategies; define
- Relate prevention strategies to Problem areas
- Project Problems/Solutions onto illustrative accidents
- Group prevention strategies into meaningful research areas; formulate safety investment recommendations
- Assess potential payoff (in terms of reducing future fatalities).
- Recommend improvements in the format and content of helicopter accident and incident information

Chain of Event Categories

Category	Examples of Events
Preliminary events	***Definition:*** Factors that influenced the accident but were not directly related to actions taken by those involved in the accident ***Examples:*** Poor pilot health, limited pilot expereince, adverse Wx
Preflight events	***Definition:*** Events that occurred prior to helo departure on accident flight that could have influenced the outcome. ***Examples:*** Obtaining Wx briefing in bad weather, or ensuring the aircraft had enough fuel are examples.
Flight-related events	***Definition:*** Events or actions that occurred during the flight that were associated with the accident. ***Examples:*** Continued flight into adverse Wx, poor ATC vectoring
Emergency-related events	***Definition:*** Events that occurred during the accident sequence itself. ***Examples:*** Poor landing site selection, wire strike, fuel starvation
Survival-related events	***Definition*:** Events or actions that did, or could have, influenced occupant survival after the accident. ***Examples:*** Helmet use, delayed rescue, inop ELTs

Development of Illustrative Chains of Events

Eventsum	Events	EMS1	EMS2	EMS3	GM1	GM2	GM3	SS1	SS2	SS3	ENG1
Prelim Info	Night	A	B			B					A
	Adverse Weather	A				B		A			
	Mangement/ job assignment		B			B					
	Pilot health		B								
	Improper maint/inspection				A				B		A
	Military surplus aircraft/parts								B		
	Limited pilot expereince	A							B		A
	Personal stress										A
	Urgency of mission	A									
	Language difficulty										
Preflt	Received Wx brief	A	B			B		A			A
	Poor flight planning	A	B	C		B		A	B		A
	Company flight following	A	B	C		B		A			
	Poor safety briefing								B		
	Poor fuel planning					B					
	Poor instructor oversight										
	Fuel contamination/fueling										
	Mission urgency	A									
Flight	Continued flt into poor vis	A				B		A			A
	Did not declare emerg/IFR	A				B		A			A
	ATC vectoring inadequate		B								
	Poor use of/inadequate nav aids		B								
	Poor a/c location/sit aware	A	B					A			
	No warning of rising terrain		B					A			
	Continued flt w/ sys warning										A
	External load overgross										
	High altitude			C							
Emerg	Wire strike	A									
	Unability to know what pilot did	A	B		A	B		A			A
	Potential loss of spatial orientatio	A				B		A			
	Poor landing site selection			C							A
	.										
	.										

Hypothetical Chain of Events x Potential Solutions

Preliminary Information	
Night	E/S Vision;
Weather	Pre-flt Planner
Limited plt exp	Basic, trans, emergtrain/exper
Urgent mission	Co policies; Pre-flt risk assess sys
Preflight	
Wx brief received	
Poor flt planning	Pre-flt Planner
Company flight foll	Automated flt following
Flight	
Cnt'dd flt poor vis	E/S Vision;ADM train; inadv IMC policy
No emergency/IFR	Recov from IMC train; IFR equip helo
Poor A/C location SA	Electronic map+position+Wx+hazards
Emergency	
Wire strike	Obs detect/alert; Elec map+wire cut
Uncertain activity	CVR/FDR; improved reports
Spatial disorientation	E/S Vision; Plt Assoc for R/C
Survival	
Occupant thrown AC	Restraint systems; Pre-flt pax brief
ELT Inoperative	Crash-resistent ELTs

Problems

Problems/accident: Range = 3-21; Average = 16

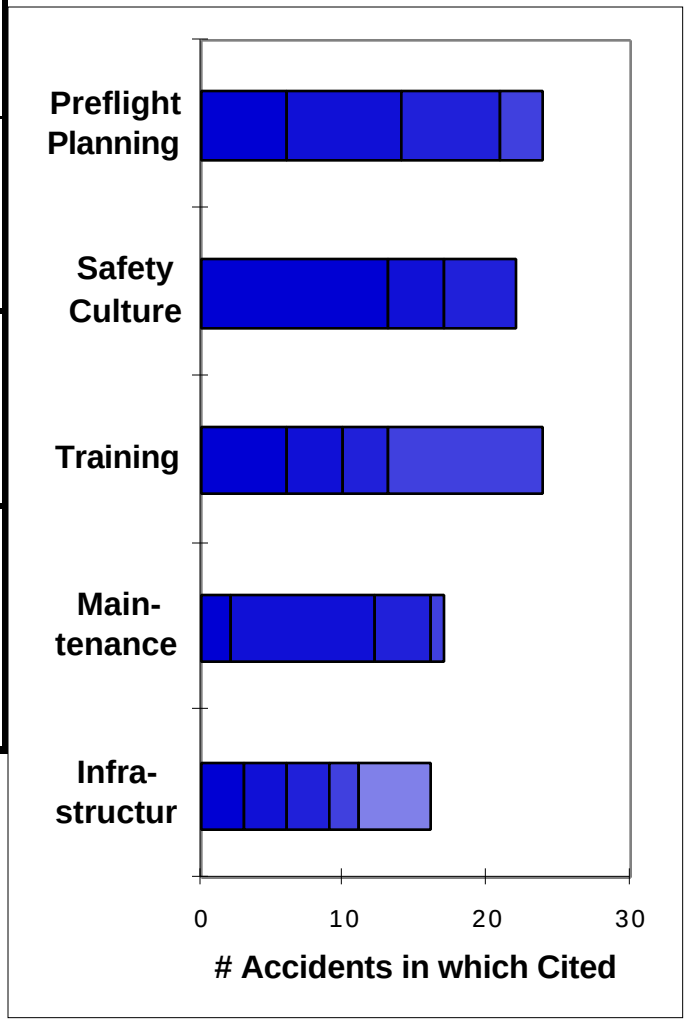
Description: Problem "data" are assertions about or descriptions of issues or deficiencies noted by team

Presentation: The number of accidents in which the team identified a type of problem are presented as a rough measure of how prevalent it was

Organization: The problems were grouped into 56 subcategories, which were in turn combined into14 categories related to flight readiness, inflight, post-crash, and data issues

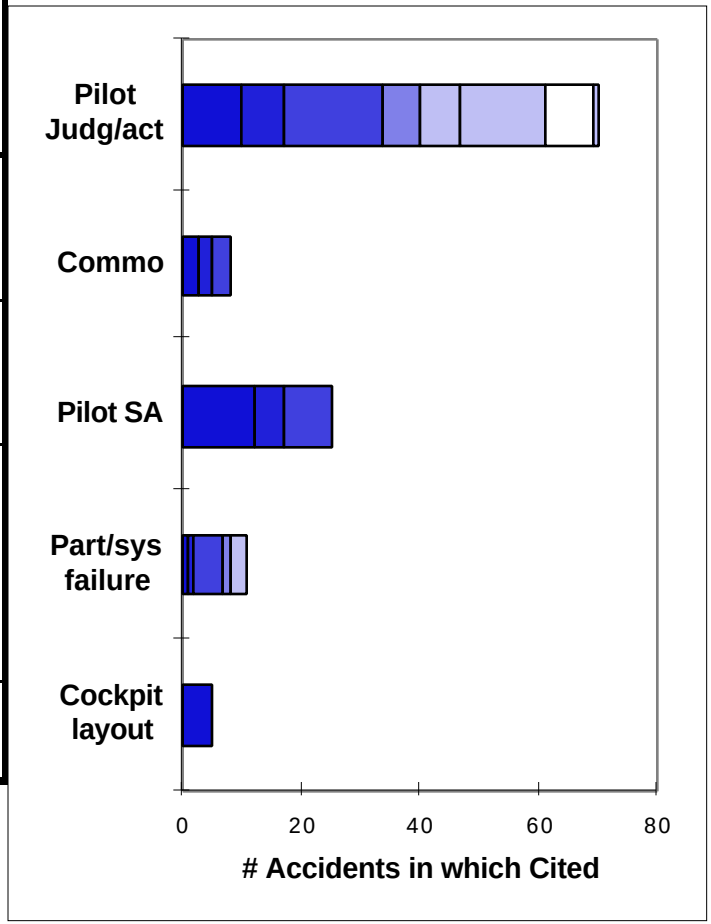
Flight Readiness Problems

Category	SubCategory	#
Preflight Planning	Acft/op limits not considered	6
	Wx/wind not considered	6
	Mission rqmts/conting ignored	8
	Pre flight process inadequate	7
	Pax safety brief inadequate	3
Safety Culture	Mgmt policies/oversight inadeq	13
	Safety prgm/risk mgmt inadeq	13
	Helicopter not IFR equipped	4
	Didn't address plt health prblms	5
Training	Emergency training inadequate	6
	Special opn training inadequate	4
	Training vehicle too unforgiving	3
	Plt inexper w/ area, mission, helio	11
Main-tenance	Tools to detect part fail inadeq	5
	Bogus/surplus/unappr parts used	2
	Improper procedures/supervision	10
	Inadequate documentation	4
	Comp used not built to mfg spec	1



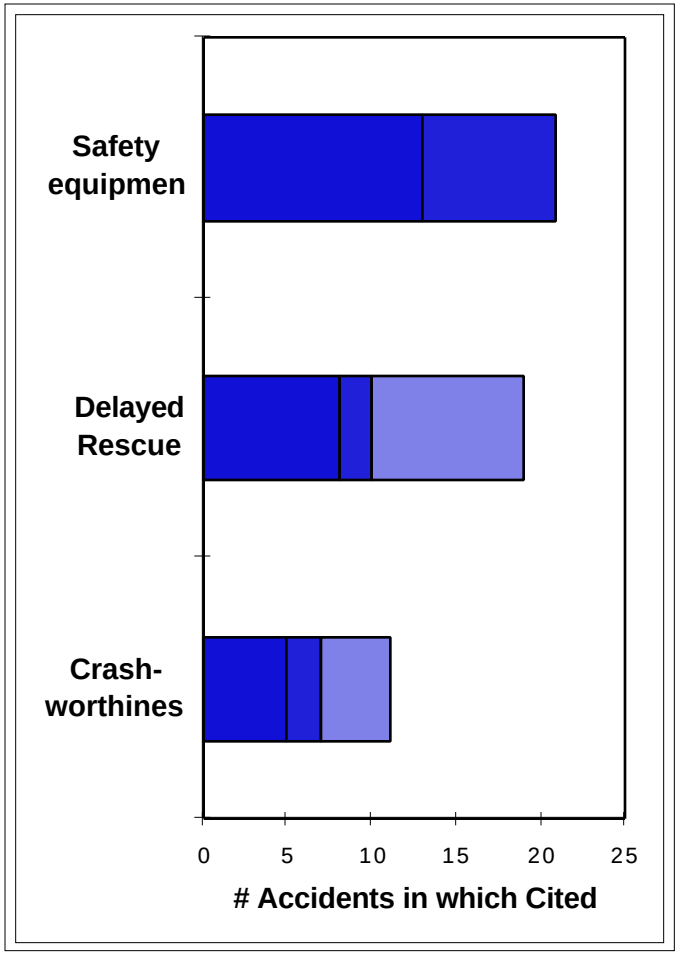
Inflight Problems

Category	SubCategory	#
Pilot judg-ment & actions	Sense of urgency>risk taking	10
	Diverted attention, distraction	7
	Flight profile unsafe for cond	17
	Poor cockpit resource mgmt	6
	Perceptual judgment errors	7
	Failed to follow procedures	14
	Pilot control/hndl deficiencies	8
	Used unauthorized equipment	1
Commu-nications	Coord w/ground personnel	3
	Coordination with ATC	2
	Coordination with other pilots	3
Pilot situation awareness	Aircraft position and hazards	12
	Aircraft state	5
	Local and enroute weather	8
Part/ system failure	Main rotor	1
	Hydraulic system	1
	Engine (partial or total)	5
	Gear	1
	Tail rotor/tail boom	3
Cockpit layout	Poor positioning of cntrl/instru	5

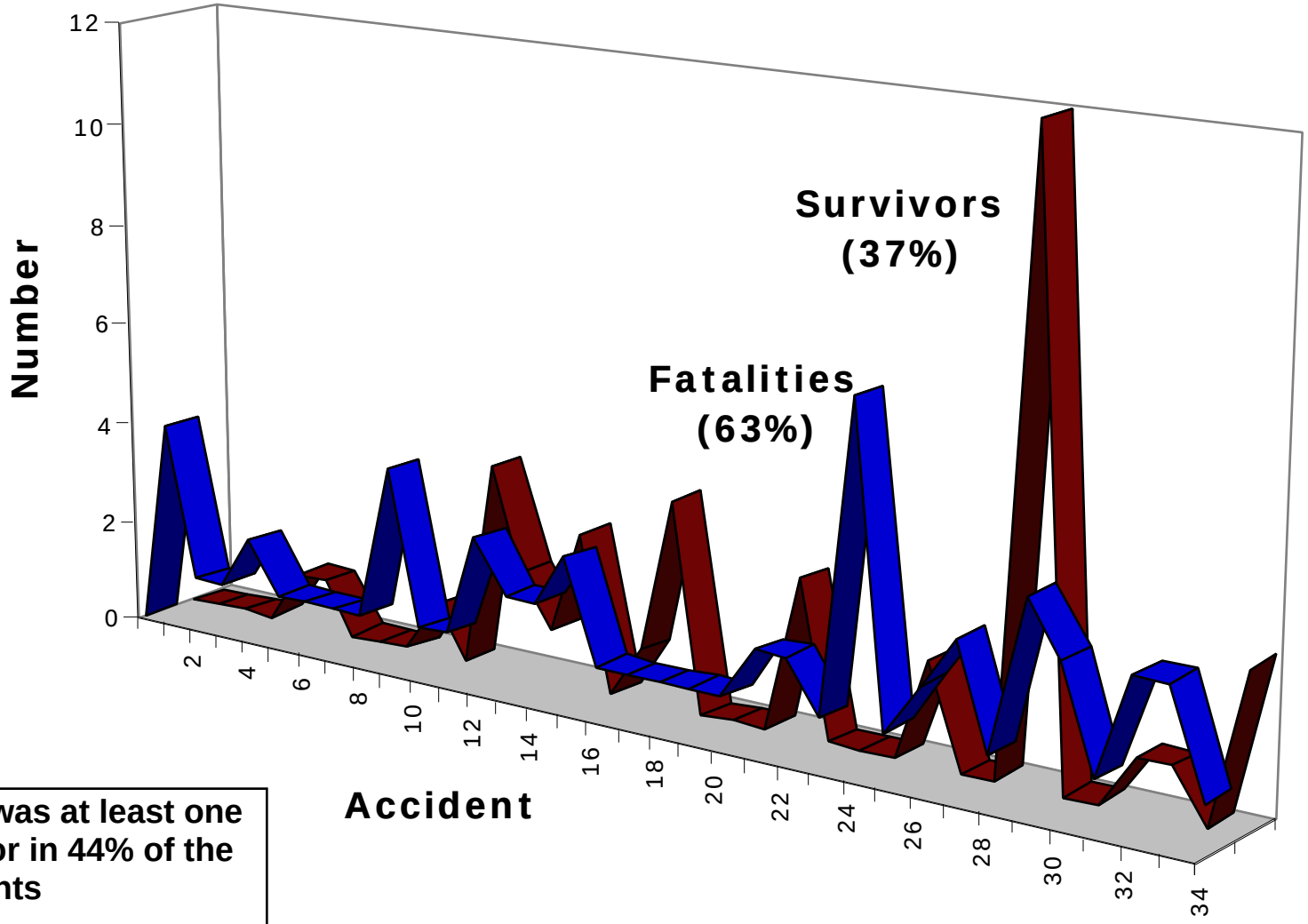


Post-Crash SurvivabilityProblems

Category	SubCategory	#
Safety equipment	Safety eqpt not installed/ failed	13
	Pax/crew survival gear not used	8
Crash-worthiness	Vehicle did not withstand impact	8
	Vehicle sank and/or capsized	2
	Post-crash fire	9
Delayed rescue	ELT inop/damaged by impact	5
	Inaccessible accident site/bad Wx	2
	No flt follow - slow to locate site	4



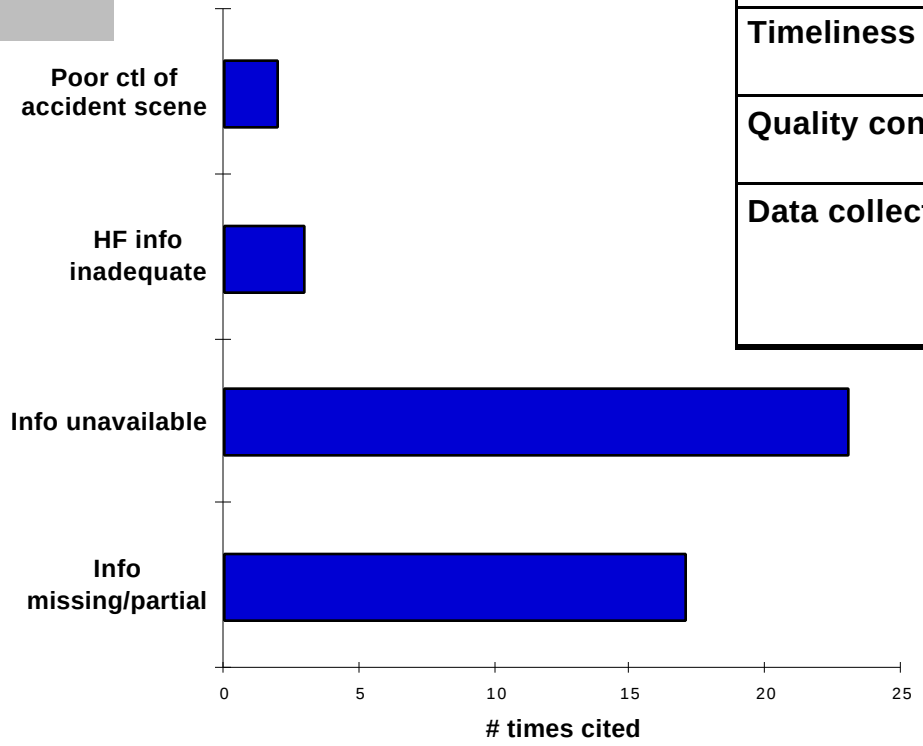
Accident Survivability



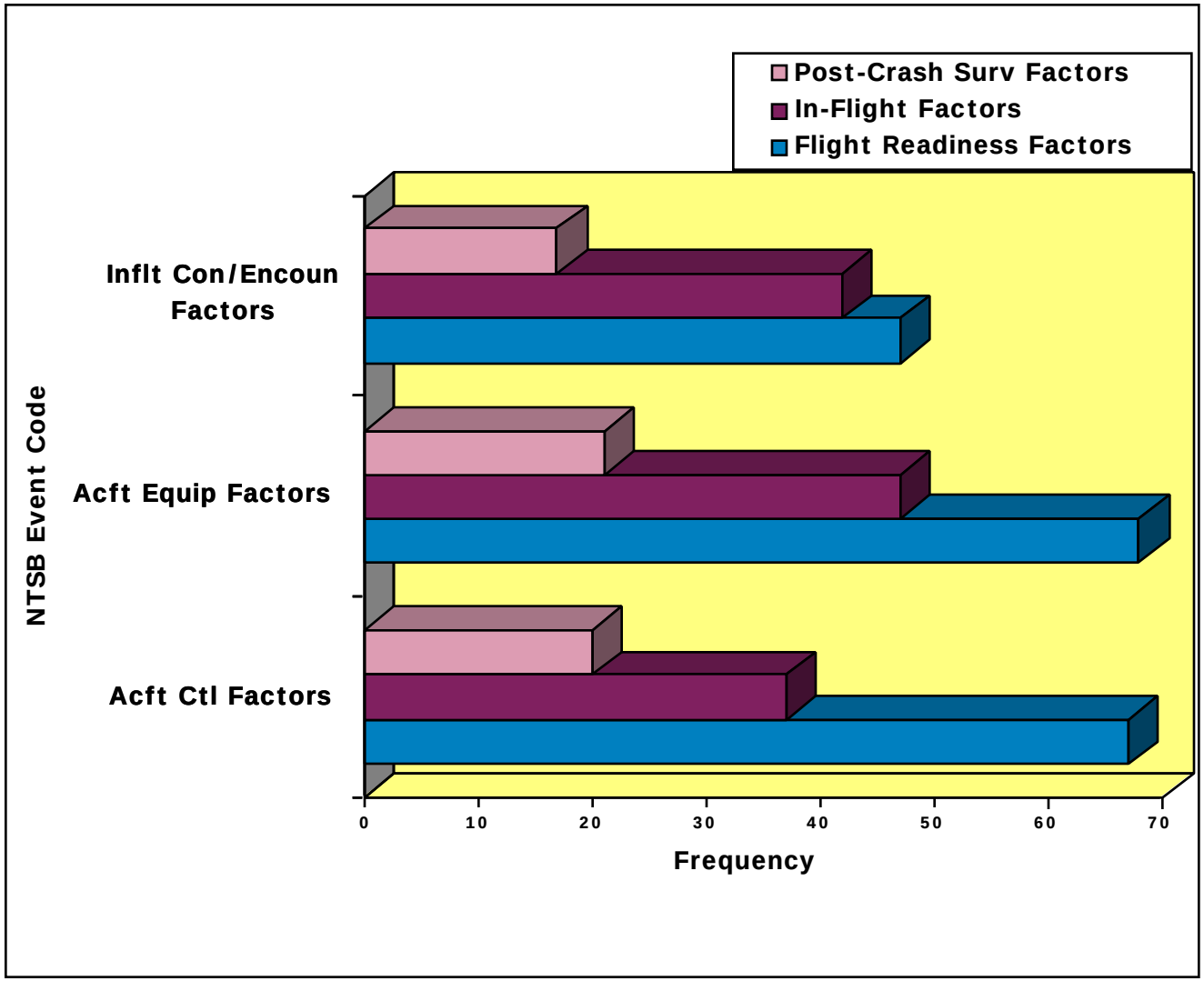
There was at least one survivor in 44% of the accidents

Data/Database Problems

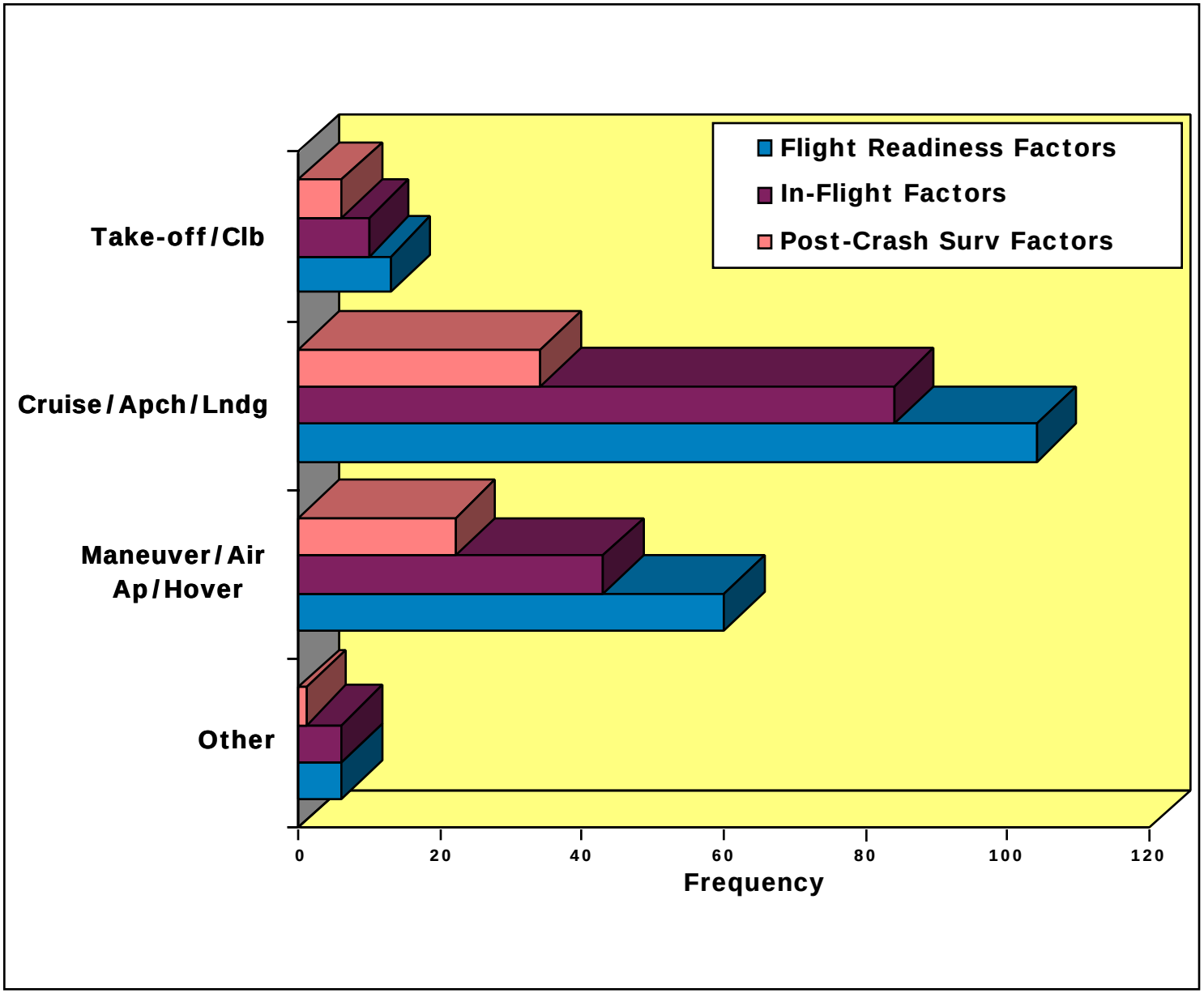
Topic	Description
Missing Data	· Missing data creates problems for analysts Special problem for R/C & GA (data acquisition is decentralized)
Standardi-zation	· Field domain values are not standardized sufficiently
Incomplete reports	· Some reports finalized with data missing (narratives)
Classification logic	· Classification logic by type of flying (GENAVN, SCH121) questionable
Timeliness	· Lag between time of accident and entry of data into the system
Quality control	· Reports contain inconsistent Misspellings and jargon confound analysis
Data collection	· Data collected does not always focus on key problem areas (e.g., human factors) Quality of data collection reflects visibility of accident



Relationship to NTSB Event Codes



Relationship to NTSB Phase of Flight Codes



Solutions

Potential Solutions/accident: Range: 4-25; Average: 13

Description: Solutions are technologies or changes in procedures/policies that might have broken one link in the chain of events for one accident, or targeted underlying Problems. There may have been several Solutions suggested for any problem.

Presentation: The number of accidents for which the team suggested a type of Solution are presented as a rough measure of its potential utility for these 34 accidents.

Organization: The Solutions were grouped into 54 subcategories, which were in turn combined into 8 categories related to helicopter operations, design, and maintenance, data issues, and infrastructure.

Solutions

Solution Category	Solution Subcategory	#
Situation displays	· Ground prox warn sys for helo	5
	· Electronic map/position	7
	· Miscellaneous	2
	· Obstacle detection & alerting	14
	· Radar alt/dist from grnd/water	9
	· Enhanced/synthetic vision	10
	· Weather display and alterting	6
Pilot Aiding/ Auto-mation	· Pilot's Associate for RC	8
	· Autorotation display/aid	2
	· Envelope Limiting	3
	· Automatic flight following	6
	· PC-Based Pre-Flight Planner	11
	· PC-Based Risk Assess Sys	8
	· Attitude hold/stabilization	1

Solutions

Solution Category	Solution Subcategory	#
Safety culture of organ	· Adequately equip helo for mission	3
	· Inadvertent IMC policy	2
	· Formalize pax pre-flt brief	4
	· Company policies	11
Training	· Aero decision making	14
	· Basic trng materials/syllabus	12
	· CRM	2
	· Recognize/resolve emrg	5
	· FW-RW transition	3
	· Ground personnel	7
	· Recover from IMC/IFR	3
	· Sim facilities for helo	9
	· Unique ops/mnvers/missions	11

Solution Category	Solution Subcategory	#
Helicopter design & perf	· HUMS	17
	· Icing protection	0
	· Misc design improvements	10
	· Improved man/machine interface	3
	· Change in rotor design/function	3
	· Real-time perfmonitoring	12
	· Low-speed wind sensors	4
	· Wire cutters/hardened blades	2
Main-tenance	· Maint issues for surplus mil	2
	· Non destructive inspection techniques	7
	· Impr maint proc/quality cntrl	11

Solutions

Solution Category	Solution Subcategory	#
Post-Crash Survival	· Improved crashworthiness	6
	· Crash-survivable ELT	5
	· Survivability equipment	9
	· Flotation systems	9
	· Crash resistant fuel system	13
	· Restraint systems	10

Information Added by Analysis Process

NTSB Description	PROBLEM SubCategories	SOLUTION SubCategories
Event: 220 Inflt cllsn w/ obj Phase of Flight 540 (Cruise) Cause: 24023-3114-4000 Flt into known adv Wx-intent-PinC Cause: 24015-3102-4000 VFR flt into IMC-Cont-PinC Cause: 24518-3109-4000 Alt-improp-PinC	Inadequate plt exper-area,vehicle, mission Training inadequate for inadv IMC Sense of rgency > taking risks Preflight-ignored mission rqmts/conting Preflight- inadequate/ hasty Preflt-Wx not considered Perceptual/judgment errors Poor SA (local/enroute Wx) Poor SA (position/hazards) Adequately equip helio for mission Tower/wire markings inadequate Info unavailable to investigators Info not in report	Company policies Recovery from inadv IMC training PC-based risk asses sys Accurate Wx info at dispatch PC-based pre-flight planner Aero decision making training Radar altimetry forward and down Ground prox warning for helio Display of map+Wx +hazards+position E/S vision system Review twr/wire mark rqmts Improved helio crshwrthnss CVR/FDR Imprv data acq

Examples of Safety Investment Areas

- CAVR/FDR
- HUMS (for maintainers & inflight)
- Cockpit information displays (e.g., E/S Vision, moving map, decision aids, obstacle detection)
- Training aids
- Tools for pre-flight planning.
- Tools to acquire, maintain, analyze & use safety data
- Methods to predict/measure safety improvements
- Automatic flight monitoring system
- Disseminate aircraft-centered, low-altitude Wx info

Status

- 34 fatal helicopter accidents analyzed
- Chain-of-Event, Problem and Solution databases developed, coded, and summarized
- Cross-correlation with NTSB codes completed
- Illustrative “accidents” created; narratives drafted, graphic re-enactments under development
- Safety Research Areas identified; narratives and recommendations being drafted
- Draft report being reviewed by team members
- Detailed analysis of helicopter incident data by ASRS staff requested